

PATENT

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PATENT APPLICATION

FOR

HEATING CONFIGURATION FOR USE

IN THERMAL PROCESSING CHAMBERS

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HEATING CONFIGURATION FOR
USE IN THERMAL PROCESSING CHAMBERS

5 Background of the Invention

10 A thermal processing chamber as used herein
refers to a device that rapidly heats objects, such
as semiconductor wafers. Such devices typically
include a substrate holder for holding a
15 semiconductor wafer and a light source that emits
light energy for heating the wafer. During heat
treatment, the semiconductor wafers are heated
under controlled conditions according to a preset
temperature regime. For monitoring the temperature
20 of the semiconductor wafer during heat treatment,
thermal processing chambers also typically include
temperature sensing devices, such as pyrometers,
that sense the radiation being emitted by the
semiconductor wafer at a selected band of
wavelengths. By sensing the thermal radiation
being emitted by the wafer, the temperature of the
wafer can be calculated with reasonable accuracy.

25 In alternative embodiments, instead of or in
addition to using radiation sensing devices,
thermal processing chambers can also contain
thermocouples for monitoring the temperature of the
wafers. Thermocouples measure the temperature of
objects by direct contact.

30 Many semiconductor heating processes require a
wafer to be heated to high temperatures so that
various chemical and physical reactions can take
place as the wafer is fabricated into a device.
During rapid thermal processing, which is one type
of processing, semiconductor wafers are typically
35 heated by an array of lights to temperatures, for
instance, from about 400°C to about 1,200°C, for

times which are typically less than a few minutes. During these processes, one main goal is to heat the wafers as uniformly as possible.

Problems have been experienced in the past, however, in being able to maintain a constant temperature throughout the wafer and in being able to control the rate at which the wafer is heated. If the wafer is heated nonuniformly, various unwanted stresses can develop in the wafer. Not being able to heat the wafers uniformly also limits the ability to uniformly deposit films on the wafers, to uniformly etch the wafers, beside limiting the ability to perform various other chemical and physical processes on the wafers.

Temperature gradients can be created within the wafer due to various factors. For instance, due to the increased surface area to volume ratio, the edges of semiconductor wafers tend to have a cooling rate and a heating rate that are different than the center of the wafer. The energy absorption characteristics of wafers can also vary from location to location. Additionally, when gases are circulated in the chamber, the gases can create cooler areas on the wafer due to convection.

In the past, various lamp configurations have been proposed in order to overcome the above described deficiencies and improve the ability to heat wafers more uniformly and to control the temperature of the wafers at various locations. These systems, however, have become increasingly complex and expensive to produce. For instance, some systems can contain well over 100 lamps.

As such, a need currently exists for an improved thermal processing chamber that is capable of uniformly heating semiconductor wafers in a

relatively simple manner without being as complex as many prior art systems. A need also exists for an improved rapid thermal processing chamber for heating semiconductor wafers that is equipped with controls for varying the amount of energy that is applied to the wafer at different locations based upon the characteristics and properties of the wafer. Such controls are especially necessary due to the increasing demands that are being placed upon the preciseness at which the semiconductor wafers are heat treated and at which semiconductor devices are fabricated.

Summary of the Invention

The present invention is generally directed to an apparatus for heat treating semiconductor wafers. The apparatus includes a thermal processing chamber adapted to contain a semiconductor wafer. For instance, a substrate holder can be contained within the chamber upon which the wafer is held. A heating device is placed in communication with the thermal processing chamber which emits thermal light energy onto the wafer held on the substrate holder. The heating device can include an assembly of light energy sources which are positioned, for instance, to heat different zones of the wafer. The light energy sources form an irradiance distribution across a surface of the wafer.

In particular, the light energy sources used in the present invention are linear lamps positioned above the wafer, below the wafer, or above and below the wafer. Linear lamps are elongated lamps that are typically oriented horizontally with respect to the wafer being heated. Although the lamps can be any shape, such

as circular, for most applications, the lamps have a long rod-like shape that extend the length of the wafer being heated, such as from one end of the thermal processing chamber to the other. For example, a series of rod-like lamps positioned parallel to each other, can be located over the wafer.

During the heating process, the semiconductor wafer can be rotated. In this manner, the light energy sources form radial heating zones on the wafer which aid in heating the wafer uniformly and provide good temporal control during the heating cycle.

In accordance with the present invention, the heating device further includes at least one tuning device positioned amongst the linear lamps. The tuning device is configured to change the irradiance distribution of the linear lamps in a manner for more uniformly heating the semiconductor wafer.

The tuning devices provide localized temperature control on the wafer. Through the combination of linear lamps and tuning sources, the present invention allows the processing system to achieve a better temperature uniformity across the wafer or a better realization of a desired temperature profile. In one embodiment, the system can also be used to radially fine tune the whole wafer for further improving temperature uniformity.

The tuning device used in the present invention can be any suitable lamp or lamp configuration that is capable of directing a focused light beam onto a certain location of a substrate. For instance, in one embodiment, the tuning device can be a laser. The laser can emit p-

polarized light onto the wafer. In order to maximize absorption, the laser can be adjusted so that the angle of incidence corresponds to where reflectivity of the light at the particular wavelength is at a minimum. For example, when processing silicon wafers, the angle of incidence can be generally less than 90°, and particularly from about 40° to about 85°.

Further, since most lasers emit light at a particular wavelength, in an alternative embodiment of the present invention, multiple lasers can be used that emit light at different wavelengths. By using different types of lasers, problems associated with reflectivity can be minimized.

Besides lasers, arc lamps can also be used as the tuning device. Arc lamps are well suited to emitting light that can be focused onto a particular portion of the wafer. When used in the system of the present invention, an arc lamp can be coupled to a light pipe and at least one focusing lens for directing light being emitted by the arc lamp onto a particular location.

The system of the present invention can include as many tuning devices as are required for uniformly heating wafers. The number of tuning devices incorporated into a particularly system will generally depend upon numerous factors, including the configuration of the light energy sources.

In order to control the amount of light energy that is emitted by the plurality of light energy sources, the apparatus of the present invention can include at least one temperature sensing device which senses the temperature of the wafer at a plurality of locations. For instance, the

temperature sensing device can be a plurality of pyrometers, one pyrometer with multiple viewing ports, or one or more thermocouples. The temperature sensing devices can be in communication with a controller, such as a microprocessor, which determines the temperature of the wafer. The controller, in turn, can be in communication with the power supply of the linear lamps for controlling the amount of heat being emitted by the light energy sources in response to the temperature of the wafer. The controller can be configured, for instance, to control the amount of light energy being emitted by each linear lamp or can control different groups of the light energy sources.

In one embodiment, the controller can be configured to also control the amount of light energy that is being emitted by a tuning device installed in accordance with the present invention. In particular, the controller can be used to control the tuning device independent of the linear lamps. Further, the controller can also be configured to be capable of automatically moving the support structure upon which the tuning device is mounted in order to change and adjust the location of where the light energy being emitted by the tuning device contacts the wafer.

Other features and aspects of the present invention are discussed in greater detail below.

Brief Description of the Drawings

A full and enabling disclosure of the present invention, including the best mode thereof, directed to one of ordinary skill in the art, is set forth more particularly in the remainder of the specification, which makes reference to the appended figures in which:

Figure 1 is a cross-sectional view of one embodiment of a thermal processing chamber that may be used in accordance with the present invention;

Figure 2 is a cross-sectional perspective view of one embodiment of a heating device that may be used in thermal processing chambers made in accordance with the present invention;

Figure 3 is a cross-sectional perspective view of the heating device illustrated in Figure 2;

Figure 4 is a perspective view of the heating device illustrated in Figure 2;

Figure 5 is a bottom view of the heating device illustrated in Figure 2; and

Figure 6 is a side view of one embodiment of a tuning device made in accordance with the present invention.

Repeat use of references characters in the present specification and drawings is intended to represent same or analogous features or elements of the invention.

Detailed Description of the Preferred Embodiments

It is to be understood by one of ordinary skill in the art that the present discussion is a description of exemplary embodiments only, and is not intended as limiting the broader aspects of the present invention, which broader aspects are embodied in the exemplary construction.

A rapid thermal processing apparatus uses intense light to heat a semiconductor wafer as part of the manufacturing process of integrated circuits. Exposure to light energy causes a rapid increase in the temperature of a semiconductor wafer and allows processing times to be relatively short. In rapid thermal processing systems, it is important to radiate the wafer with very high

intensity light in a very uniform and controlled fashion. As stated above, the difficulty with current devices is that the requirements for the intensity of the radiated light and the ability to heat wafers uniformly are very difficult to achieve.

In general, the present invention is directed to an apparatus and method for heating semiconductor wafers uniformly and at a controlled rate. The apparatus includes a thermal processing chamber in communication with a heating device that is used to heat treat semiconductor wafers contained in the chamber. The heating device contains a plurality of lamps that are positioned at preselected locations for heating the wafers. The lamps emit light energy and form an irradiance distribution over the surface of the wafer.

The heating device and processing chamber of the present invention are particularly designed to operate with linear lamps. As used herein, a "linear lamp" refers to a lamp that is designed to emit most of its energy through the longest dimension of the lamp. For instance, in most embodiments, linear lamps emit the majority of their energy through the side of the lamp. Thus, when heating semiconductor wafers, the lamps are typically horizontally oriented over and/or below the wafers.

Recently, as opposed to using linear lamps, many thermal processing chambers have been made with vertically oriented lamps. These lamps are designed to emit energy out of an end of the lamp for heating the wafers. The present inventors have discovered that using linear lamps provide various advantages over vertical lamps. For instance, when

using linear lamps, a much smaller number of lamps are required to be incorporated into the heating device, since a linear lamp can heat a much larger area than a vertical lamp. Because less lamps are required, the system generally becomes more reliable and easier to maintain. Further, the linear lamps provide good heating uniformity and make it much easier to heat a wafer from both sides of the wafer.

During heating, the wafer is rotated with respect to the plurality of lamps. In this manner, the lamps form radial heating zones on the wafer. The energy supplied to each heating zone can be controlled while the wafer is being heated.

In one embodiment, the temperature at different locations of the wafer is monitored. Based upon the temperature sensed at the different locations, the energy being emitted by the lamps is selectively controlled.

In accordance with the present invention, the heating device in communication with the thermal processing chamber further contains tuning devices which are designed to modify the irradiance distribution of the heating lamps for more uniformly heating the semiconductor wafer. The tuning devices allow fine adjustments to be made to the wafer irradiance distribution pattern in order to heat the wafer under a more controlled temperature regime and more uniformly. The tuning device can be, in one embodiment, a localized and focused source of light energy that can be directed onto a particular location on the wafer.

The tuning device can be an active localized source such as a tungsten halogen bulb in an optical configuration, an arc lamp, or a laser

diode with relatively high power.

Referring to Figure 1, a system generally 10
made in accordance with the present invention for
heat treating a wafer made from a semiconductive
5 material, such as silicon, is illustrated. System
10 includes a processing chamber 12 adapted to
receive substrates such as a wafer 14 for
conducting various processes. As shown, wafer 14
is positioned on a substrate holder 15 made from a
10 thermal insulating material such as quartz.
Chamber 12 is designed to heat wafer 14 at very
rapid rates and under carefully controlled
conditions. Chamber 12 can be made from various
materials, including metals and ceramics. For
15 instance, chamber 12 can be made from stainless
steel or quartz.

When chamber 12 is made from a heat conductive
material, preferably the chamber includes a cooling
system. For instance, as shown in Figure 1,
20 chamber 12 includes a cooling conduit 16 wrapped
around the perimeter of the chamber. Conduit 16 is
adapted to circulate a cooling fluid, such as
water, which is used to maintain the walls of
chamber 12 at a constant temperature.

25 Chamber 12 can also include a gas inlet 18 and
a gas outlet 20 for introducing a gas into the
chamber and/or for maintaining the chamber within a
preset pressure range. For instance, a gas can be
introduced into chamber 12 through gas inlet 18 for
30 reaction with wafer 14. Once processed, the gas
can then be evacuated from the chamber using gas
outlet 20.

Alternatively, an inert gas can be fed to
chamber 12 through gas inlet 18 for preventing any
35 unwanted or undesirable side reactions from

occurring within the chamber. In a further embodiment, gas inlet 18 and gas outlet 20 can be used to pressurize chamber 12. A vacuum can also be created in chamber 12 when desired, using gas outlet 20 or an additional larger outlet positioned beneath the level of the wafer.

During processing, substrate holder 15, in one embodiment, can be adapted to rotate wafer 14 using a wafer rotation mechanism 21. Rotating the wafer promotes greater temperature uniformity over the surface of the wafer and promotes enhanced contact between wafer 14 and any gases introduced into the chamber. It should be understood, however, that besides wafers, chamber 12 is also adapted to process optical parts, films, fibers, ribbons, and other substrates having any particular shape.

A heat source or heating device generally 22 is included in communication with chamber 12 for heating wafer 14 during processing. Heating device 22 includes a plurality of linear lamps 24, such as tungsten-halogen lamps. As shown in Figure 1, lamps 24 are horizontally aligned above wafer 14. It should be understood, however, that lamps 24 may be placed at any particular location such as only below the wafer or above and below the wafer. Further, additional lamps could be included within system 10 if desired.

The use of linear lamps 24 as a heat source is generally preferred. For instance, lamps have much higher heating and cooling rates than other heating devices, such as electrical elements or conventional furnaces. Lamps 24 create a rapid isothermal processing system that provide instantaneous energy, typically requiring a very short and well controlled start up period. The

flow of energy from lamps 24 can also be abruptly stopped at any time. As shown in the figure, lamps 24 are equipped with a gradual power controller 25 that can be used to increase or decrease the light energy being emitted by any of the lamps.

In order to assist in directing the light energy being emitted by lamps 24 onto wafer 14, the lamps can be associated with a reflector or a set of reflectors. For instance, as shown in Figure 1, the heating device 22 includes a reflector plate 36 positioned above the linear lamps 24. Reflector plate 36 can be made from any material suitable for reflecting light energy and can have any suitable shape that will assist in directing the light energy toward the wafer 14.

In order to monitor the temperature of wafer 14 during the heating process, in this embodiment, thermal processing chamber 12 includes plurality of radiation sensing devices generally 27. Radiation sensing devices 27 include a plurality of optical fibers or light pipes 28 which are, in turn, in communication with a plurality of corresponding light detectors 30. Optical fibers 28 are configured to receive thermal energy being emitted by wafer 14 at a particular wavelength. The amount of sensed radiation is then communicated to light detectors 30 which generate a usable voltage signal for determining the temperature of the wafer which can be calculated based, in part, on Planck's Law. In one embodiment, each optical fiber 28 in combination with a light detector 30 comprises a pyrometer. In another embodiment, the optical fibers 28 are routed to a single but multiplexing radiation sensing device.

In general, thermal processing chamber 12 can

contain one or a plurality of radiation sensing devices. In a preferred embodiment, as shown in Figure 1, thermal processing chamber 12 contains a plurality of radiation sensing devices that measure the temperature of the wafer at different locations. Knowing the temperature of the wafer at different locations can then be used to control the amount of heat being applied to the wafer as will be described in more detail hereinafter. The amount of heat applied to various zones of the wafer can also be controlled in an open loop fashion. In this configuration the ratios between the various heating zones can be pre-determined after manual optimization.

System 10 further includes a window 32 which separates lamps 24 from the chamber. Window 32 serves to isolate lamps 24 from wafer 14 and prevent contamination of the chamber. Window 32 as shown in Figure 1 can be a window positioned between chamber 12 and heat source 22. In an alternative embodiment, each lamp 24 can be covered by a separate window casing.

Besides using radiation sensing devices, other temperature sensing devices may be used in the system of the present invention. For instance, one or more thermocouples may be incorporated into the system for monitoring the temperature of the wafer at a single location or at a plurality of locations. The thermocouples can be placed in direct contact with the wafer or can be placed adjacent the wafer from which the temperature can be extrapolated.

System 10 further includes a system controller 50 which can be, for instance, a microprocessor. Controller 50 receives voltage signals from light

detectors 30 that represent the radiation amounts being sampled at the various locations. Based on the signals received, controller 50 is configured to calculate the temperature of wafer 14 at different locations.

System controller 50 as shown in Figure 1 can also be in communication with lamp power controller 25. In this arrangement, controller 50 can determine the temperature of wafer 14, and, based on this information, control the amount of thermal energy being emitted by lamps 24. In this manner, instantaneous adjustments can be made regarding the conditions within reactor 12 for processing wafer 14 within carefully controlled limits.

In one embodiment, controller 50 can also be used to automatically control other elements within the system. For instance, controller 50 can be used to control the flow rate of gases entering chamber 12 through gas inlet 18. As shown, controller 50 can further be used to control the rate at which wafer 14 is rotated within the chamber.

As described above, the present invention is generally directed to a particular heating configuration that is used within thermal processing chamber 12. Referring to Figures 2 through 5, one embodiment of a heating device 22 that can be used in combination with thermal processing chamber 12 in accordance with the present invention is illustrated. As shown, heating device 22 includes a plurality of light energy sources, such as linear lamps 24 that are secured to a mounting base 34. The linear lamps 24 each have a length that extends approximately the width of the thermal processing chamber. The

linear lamps 24 are placed in a parallel configuration and are horizontally oriented with respect to a wafer being heated. For example, referring to Figure 5, the semiconductor wafer 14 is shown in phantom for providing a visual comparison between the linear lamps 24 and the diameter of the wafer.

In accordance with the present invention, in order to heat a wafer more uniformly, heating device 22 further includes tuning devices 40 which, in this embodiment, are generally positioned in between the linear lamps 24. Tuning devices 40 are designed to emit controlled and focused amounts of light energy onto particular locations of a semiconductor wafer being heated. The tuning devices are provided in order to make fine adjustments to the irradiance distribution produced by lamps 24 in order to more precisely heat the wafers. For example, tuning devices 40 can be used to emit controlled amounts of light energy between the radial heating zones located on the wafer.

Tuning devices 40 as shown in Figures 2 through 4 are active localized sources of focused light energy. The tuning devices can be, for instance, laser diodes having a relatively high power. For instance, the tuning source can contribute from about 1% to about 30% of the local power density irradiating the wafer at the selected position. In an alternative embodiment, tuning devices 40 can be a lamp, such as a tungsten halogen lamp or arc lamp, in operative association with one or more focusing lenses or reflectors.

In Figures 2 through 4, tuning devices 40 include a light energy source coupled to a light pipe or a fiberoptic 78 and a focusing lens 80.

Light pipe 78 and focusing lense 80 serve to direct the light energy onto a particular location of the wafer. These elements, however, may not be necessary in all applications.

5 Instead of or in addition to conventional laser diodes, a tunable laser means can also be used as a laser source. The wavelength of light emitted by the tunable laser device can be adjustable. Consequently, the wavelength of the
10 tuning source can be adapted or adjusted to the texture or state of the illuminated wafer region, which can include structures in the lateral direction and/or structures of layers of different dielectric constants. More particularly, the
15 wavelength of the tuning source can be adjusted in order to maximize absorption.

 The number of tuning devices 40 that may be used in a system of the present invention can vary depending upon the particular application. For
20 most applications, however, tuning devices will be positioned so as to heat the outer edges of the wafer. As shown in Figure 5, many other tuning devices 40 can also be included in the system.

 During operation, heating device 22 is
25 preferably in communication with a system controller 50 as shown in Figure 1. Based upon the temperature of the wafer being heated, system controller 50 can be designed to vary the amount of light energy being emitted by lamps 24 and by
30 tuning devices 40.

 Besides light energy intensity, other parameters of the tuning device can be controlled as a function of the wafer temperature or the temperature of another part of the wafer processing
35 system. These parameters can be controlled as a

function of other parameters relevant to the processing of wafers, like e.g. process time, conditions of the processed gas such as temperature, pressure or composition, or ramp rate which refers to the rate at which the wafer is heated or cooled. Other parameters of the tuning device that can be controlled include e.g. the emitted spectrum, pulse parameters such as time, duty-factor or frequency, pulse-shape, frequency-time characteristics if the device is used in a pulse mode, the spacial position of the device relative to the wafer, the state of polarization, the size and angle of the illuminated area on the wafer, coherence in time and space, and parameters of any optical devices such as apertures, filters, lenses of various kind, mirrors which e.g. at least partly but not necessarily surround the light source of the tuning device.

Referring to Figure 6, one embodiment of a tuning device made in accordance with the present invention is illustrated. In this embodiment, like reference numerals have been used in order to indicate similar elements as shown in the other figures. As shown, tuning device 40 includes a light energy source 42 which transmits light to a wafer 14 in a thermal processing chamber through a window 32. Light energy source 42 is positioned above heating device 22, which includes a plurality of linear lamps 24.

In this embodiment, light energy source 42 is an arc lamp that includes a cathode spaced from an anode. During operation, the cathode emits electrons that travel across the lamp arc gap and strike the anode. Arc lamps typically emit ultra violet light, infrared light, and visible light. In

one embodiment, the emitted spectrum of the arc lamps can be controlled by current density. The current density can be controlled by power supply and adjusting the voltage or internal resistance of the supply. The current density, however, can also be controlled by external magnetic fields. If the arc lamps are used in a pulsed mode, a high current density is achievable, resulting in very intense emitted UV radiation.

The power level of the lamp can vary depending upon the particular application. Power levels from 125 watts to 1500 watts are available. Each of these power levels is actually a power range, with nominal power near the maximum. For most applications, however, the lamp should have a power level of from about 180 watts to about 320 watts.

As illustrated, arc lamp 42 is surrounded by a reflector 70. Reflector 70 preferably has a pure polycrystalline alumina body that is glazed with a high temperature material to give the reflector a specular surface. For instance, the reflector can be coated with a silver alloy for a visible lamp or an aluminum coating for a UV lamp and/or dielectric coating.

Reflector 70 surrounds the light energy source and can have various shapes. For instance, reflector 70 can be parabolic or elliptical. A parabolic reflector will create a collimated output beam, while an elliptical reflector will create a focused output. For most applications, preferably an elliptical reflector is used, because of its slightly better collection efficiencies and slightly shorter arc gap, while parabolic reflectors are usually used with focusing lenses.

During operation, preferably arc lamp 42 is

cooled. For example the lamp can be cooled using forced air, free convention, conduction, or can be water cooled.

5 The cathode assembly and the anode assembly of arc lamp 42 are sealed within the reflector by a lamp window 72. Lamp window 72 can be made from, for instance, a ground and polished single-crystal sapphire.

10 As shown in the Figure, light emitted by arc lamp 42 is directed through a pair of apertures or "stops" 74 and 76 to block stray light. The reflector 70 focuses the light energy into a light pipe 78. One or more lenses are then used to focus the light out of the pipe and onto the wafer
15 surface. Light pipe 78 is preferably made from a material that is well adapted for transmitting light and that is not substantially thermally conductive, such as quartz.

20 From light pipe 78, the light is passed through several focusing lenses prior contacting a semi-conductor wafer 14. For instance, as shown in the embodiment illustrated in Figure 6, the system includes a first focusing lens 80, a second focusing lens 82, and a third focusing lens 84.
25 Focusing lens 84 is positioned on the opposite side of window 32 within the thermal processing chamber in which the wafer is held. Focusing lenses 80, 82 and 84 are designed to facilitate transmission of light energy being emitted by arc lamp 42 and to
30 focus the light onto a particular location of the wafer. In this embodiment, focusing lenses 80 and 82 comprise a condensing lens set. It should be understood, however, that the number and combination of lenses can vary depending on the
35 application. For instance, the number of lenses

can be reduced with careful lens design, such as by using an aspherical lens. Alternatively or in combination also Fresnel-Zone-Plates or other refractive and/or diffractive means and/or
5 reflective optics (e.g. an elliptical reflector) can be used to get the desired illumination on the wafer.

Tuning device 40 as shown in figure 6 can be used to heat various locations of the wafer. In
10 one embodiment, however, it has been found that this configuration is particularly well adapted to heating the outer edges of the wafer, where the wafer tends to lose heat due to radiation and convection during heating cycles. In particular,
15 it has been found that the system illustrated in Figure 6 is particularly well adapted to heating the outer 3 to 5 millimeters of the wafer. It should be understood, however, that tuning device 40 can be positioned to heat other locations on the
20 wafer.

The configuration illustrated in Figure 6 represents one embodiment of a single tuning device using an arc lamp. It should be understood that more than one tuning device may be used in a single
25 system. Further, the location of the tuning device can vary. For instance, in an alternative embodiment, the tuning device can be below or on the side of the heater. Further, in one embodiment, wafer 14 can be heated from the top and
30 the bottom with the tuning devices. For example, the wafer can be heated from the bottom using a separate heating device containing various tuning devices. Further, the tuning device can be arranged in a linear position with respect to the
35 wafer or can assume an angular position with

respect to the wafer.

Besides arc lamps as shown in Figure 6, the tuning device of the present invention can also be a laser. Lasers can be used alone or in
5 combination with arc lamps.

In general, lasers emit light at a particular wavelength. Because lasers emit a narrow spectral band of radiation, however, it may be beneficial in some applications to couple the light emission from
10 the laser with the absorption properties of the wafer being heated. For instance, a wafer can be coated with a material or a thin-film stack that may be highly reflective at the wavelength at which the laser operates, which reduces the efficiency at
15 which the wafer is heated by the laser. In accordance with the present invention, however, various techniques can be used to increase absorption efficiencies when using lasers.

For example, in one embodiment, several
20 different types of lasers can be used in the heating device that each emit light at different wavelengths. Thus, when a particular substrate is highly reflective at the wavelength at which one laser operates, a second laser operating at a
25 different wavelength can be used to heat the wafer. The radiation from the different lasers may be optically combined before contacting the wafer. Alternatively, several beams of light from the different lasers could illuminate a selected area
30 of the wafer. In still another alternative embodiment, several beams of light could irradiate the same wafer radius as the wafer is rotated.

In addition to using multiple lasers at different wavelengths, the position of each laser
35 can be arranged so as to maximize absorption. More

specifically, absorption can be maximized by adjusting the plane of polarization and the angle of incidence of light being emitted by the laser with respect to the surface of the wafer.

5 For instance, the reflectivity of most surfaces is a function of the angle of incidence. Thus, changing the angle of incidence of the laser light contacting the wafer can increase absorption. In this embodiment, the laser sources can all be
10 angled so as to maximize absorption for a particular wafer. Alternatively, the angle of incidence of each laser source can be different so as to ensure that at least one of the tuning sources will have a high degree of absorption
15 during the heating process. The angle of incidence can also be a parameter which is controlled by the system controller 50 as a function of another parameter in the system, such as those mentioned above.

20 For most applications, when adjusting the angle of incidence, the laser beams of light should be placed in the p-polarization plane with respect to the wafer surface. The p-polarization plane is where in the electric field vector of the incident
25 radiation lies in the plane of incidence. The plane of incidence is the plane containing the incident beam and the normal to the wafer surface. For light with this polarization, the reflectivity of many materials, including silicon, can become
30 small for angles of incidence of less than 90° . In particular, reflectivity, which can be a function of temperature, is very low such as almost zero near a critical angle i.e. the Brewster angle. For silicon, the Brewster angle is approximately 75° .
35 Since laser beams are often inherently polarized,

altering the angle of incidence when using lasers can be particularly effective in accordance with the present invention.

For example, in one embodiment, when using a laser, the angle of incidence can be from about 40° to about 85° and particularly from about 60° to about 85° when heating a silicon wafer.

In general, any suitable type of laser can be used in the present invention. In one embodiment, a laser diode is used. Laser diodes efficiently convert electricity into laser radiation and are available in high power ratings. For example, high power devices, delivering continuous power of greater than 10 watts are currently commercially available, with emission wavelengths between 400 nm and 4000 nm. The above described lasers can be combined with beam delivery optics that reshape the emitted beam and direct it to the wafer. For example, the laser can be coupled with fiber optics for guiding the light onto a particular location of the wafer.

In an alternative embodiment, or in combination with the above embodiments, the tuning device can include a plurality of light pipes, such as optical fibers. The light energy of the tuning device can be distributed with the light pipes to at least two local areas within the chamber and/or the wafer. Preferably, the local areas are separated from each other and are illuminated by the same tuning device. The areas, however, can overlap or can be essentially identical, meaning that the two light pipes illuminate the same area. This tuning device configuration can be used for illuminating the wafer at the same region from the top and the bottom using a single tuning device,

such as having e.g. the same spectral conditions for the top and the bottom illumination.

When using a plurality of light pipes for a single tuning device, the tuning device can also include a system of apertures or aperture plates having a predetermined pattern of apertures. In this embodiment, certain light pipes can be selected from the plurality of light pipes. For example, a laser, arc lamp or halogen lamp can be placed in communication with a plurality of light pipes. One of the light pipes can then be selected for transferring the light energy to the wafer. The particular light pipes selected can control the intensity of the energy transported through the pipe, having the advantage that no power control of the light source itself is necessary. Such a control can be difficult for certain lasers (e.g. super radiating systems like a spark pumped nitrogen laser) or arc lamps (e.g. in pulsed mode with very high current density).

Alternatively, instead of using a plurality of light pipes in conjunction with the above-mentioned apertures, the intensity of the light emitted from the tuning source can be controlled using polarization filters. Further, there is also the possibility of simply turning the tuning devices on and off independent of the primary heating lamps for controlling the irradiance distribution.

So as mentioned, the electromagnetic power of the tuning devices can be delivered to the specified regions of the wafer from either above or below the wafer, or from both sides. The latter case gives the advantage of reducing the possibility that there is poor power coupling because of the presence of a reflective coating on

one side of the wafer. This concept can be applied
equally well to the arc lamps or the laser sources,
and it can be implemented by either having separate
sources built into the chamber above and below the
wafer, or through the use of light pipes as
described above e.g. fibers that transmit the
energy from the tuning device in these locations.
The tuning devices could also irradiate the wafer
edge from the side. This is especially useful in
cases where a slip-free ring (i.e. a heating ring
used to heat the edges of a wafer) is not present
in the system. Light sources to be built into the
side of the chamber, which would not interfere with
the mechanical layout of the linear lamp rays so
much, also can be used as tuning devices.
Irradiation from the side can fall directly on the
edge of the wafer, but it is also possible for the
illumination to cause light to fall on the top and
bottom surfaces of the wafer over a region close to
the edge. This light can be incident at a rather
large angle of incidence, and in this configuration
it is quite convenient to achieve angles of
incidence close to the critical angle for silicone
(approximately 75° to the normal), where power
coupling is strong, and coating effects could be
minimized.

These and other modifications and variations
to the present invention may be practiced by those
of ordinary skill in the art, without departing
from the spirit and scope of the present invention,
which is more particularly set forth in the
appended claims. In addition, it should be
understood that aspects of the various embodiments
may be interchanged both in whole or in part.
Furthermore, those of ordinary skill in the art

will appreciate that the foregoing description is by way of example only, and is not intended to limit the invention so further described in such appended claims.

100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000